THE AXIS OF ROTATION AT THE ANKLE JOINT IN MAN. ITS INFLUENCE UPON THE FORM OF THE TALUS AND THE MOBILITY OF THE FIBULA

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THE FORM OF THE TALUS

The upper articular surface of the talus is customarily described as wedge-shaped, its width diminishing from front to back. Measurements indicate that the majority of tali do, in fact, show some narrowing of this surface, but that the triangular facet at its lateral margin—articulating with the inferior transverse tibio-fibular ligament —often gives a misleading impression as to the true reduction in width (Inkster, 1927). A simple index of the degree of 'wedging' of any particular talus is obtained if this reduction (x) is divided by the length of the trochlear surface (y).

To assess the variations of 'wedging' in different specimens, 164 cartilage-covered tali—nine from fresh amputations, the remainder from dissecting-room subjects—were examined. Twelve proved unsuitable for detailed study, mainly due to osteoarthritic changes which obliterated the contours, and this paper is therefore based upon analysis of 152 specimens. For obvious reasons no dried bones are included in this series.

For convenience, the widths of the trochlear surface of each talus were measured at right angles to the medial edge; the anterior measurement was taken at the level of the front of the lateral edge, and the posterior measurement at the posterior limit of the medial articular surface. To measure the length of the trochlear surface a line was taken, parallel to its medial edge, from the point where the medial side of the triangular facet meets the posterior articular margin. The distance between the anterior and posterior limits of the articular cartilage was measured along this line.

The tali showed great variation in the degree of 'wedging', the fraction $100x/y$ ranging from 0 to 14. An attempt was made to correlate this variation with the degrees of mobility of the corresponding fibulae. The expectation was that a parallel-sided talus would be associated with a relatively fixed fibula, while a highly 'wedged' talus would require a fibula which could rotate about a vertical axis to accommodate the talus in all positions from full dorsiflexion to full plantar-flexion. Although rotation of the fibula can be demonstrated in the living body and in the preserved cadaver it is impossible in the latter to assess the range of movement. The superior tibio-fibular joint was therefore examined in each limb to assess the degree of mobility of the fibula.

THE SUPERIOR TIBIO-FIBULAR JOINT

This joint was found to vary considerably, both in form and inclination to the horizontal. However, in most cases it conformed to one of the following three general types:

Type I. The area of articular surface on the tibia is large. The surface is plane, approximately circular, nearly horizontal and usually underlying a projecting canopy of bone. Forty-one specimens with an area of articular surface greater than 20 sq.mm. were classified as type I. The majority (thirty-two tali) had an inclination to the horizontal of less than 30°.

Type II. The area of articular surface is moderately large. The surface is elliptical in shape with a curved profile fitting into a grooved facet on the head of the fibula. This type is frequently in communication with the knee joint via the synovial bursa deep to the popliteus tendon. Forty specimens were classified as type II.

Type III. The area of articular surface is small. The surface is plane but often irregular, and steeply inclined to the horizontal. Forty-two specimens with an area of articular surface less than 15 sq.mm. were classified as type III. The majority (thirty-six tali) had an inclination of more than 30° to the horizontal.

The remaining twenty-nine joints could not be assigned to any of the above groups. Many were plane joints but intermediate in area; others showed arthritic changes which made reliable measurement impossible.

By analogy with other joints, e.g. the superior radio-humeral articulation, it was considered that type I joints would be associated with freely mobile fibulae capable of undergoing axial rotation, and that type III joints would allow little axial rotation, although gliding movements in a vertical plane could take place.

It was found impracticable to attempt an assessment of the mobility of type II joints from simple measurements of area and angle of inclination. Movements at this type of joint are complex; the upper end of the fibula glides in an antero-lateral direction, its path being determined by the attachment of the interosseous membrane. This movement is associated with axial rotation of the lower end. The criteria applied to joints of types I and III to determine mobility in terms of area and steepness of joint surface are clearly inadequate here, since the movement of the head of the fibula is not one of simple rotation. For this reason, type II joints were excluded from the series when assessment was made of the range of mobility of the fibulae.

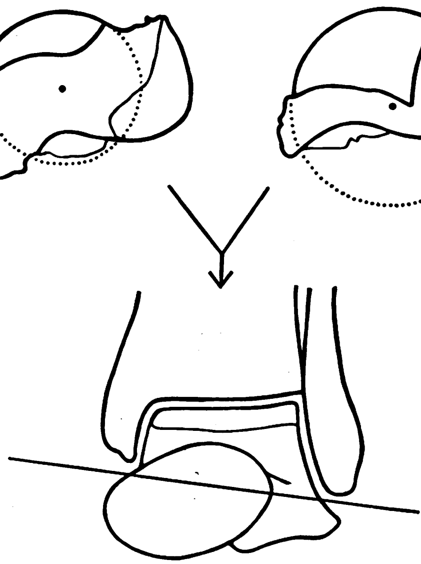
Analysis showed that no correlation existed between the mobility of the fibula and the degree of 'wedging' of the corresponding talus. Contrary to expectation, it was not unusual to find that an extremely 'wedged' talus belonged to a limb where the nature of the superior tibio-fibular joint indicated that the fibula was immobile, while many parallel-sided tali were associated with freely mobile fibulae. It seemed probable, therefore, that the variations in both the mobility of the fibula and the form of the talus might result from differences in the manner of movement of the talus in different individuals. A new study of the talus was accordingly undertaken with regard to the axis about which the bone rotates in dorsiflexion and plantar-flexion.

THE AXIS AT THE ANKLE JOINT

The axis at this joint is usually stated to be horizontal or transverse (Cunningham, 1943). Examination of the lateral and medial profiles of the trochlear surface of the talus indicates that this is rarely the case.

The lateral profile (Pl. 1, fig. 1) is almost always an arc of a true circle, and in all positions of the talus the axis of rotation must pass through the centre of this circle.

The medial profile, on the other hand, is compounded of the arcs of two circles of differing radii (Pl. 1, fig. 2). The axis of rotation is therefore a changing one. The anterior third of the medial profile is part of a circle whose radius is *less* than that of the lateral profile; in dorsiflexion, therefore, when this part of the talus is uppermost in the ankle mortice, in contact with the horizontal lower end of the tibia (Volkov, 1904), the axis of the ankle joint passes through the centre of the large lateral circle and that of the small medial circle and consequently is inclined downwards and laterally ('the dorsiflexion axis') (Text-fig. 1).



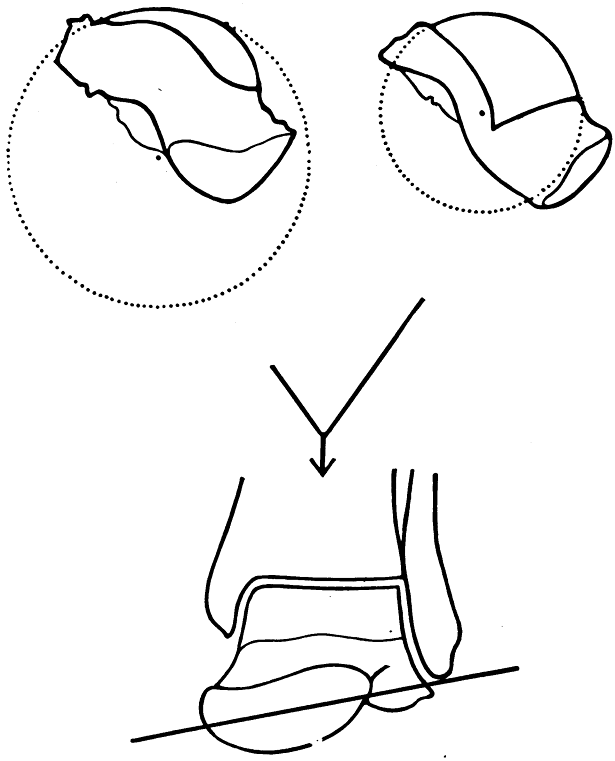
Text-fig. 1. The medial and lateral profiles of the talus in dorsiflexion. The inclination of the dorsiflexion axis (downwards and laterally) is obtained by joining the centres of rotation.

The posterior two-thirds of the medial profile is part of a circle whose radius is *greater* than that of the lateral profile; in plantar-flexion, therefore, the axis of the ankle joint is inclined downwards and medially ('the plantar-flexion axis') (Text-fig. 2).

Thus the axis of the ankle joint is not a fixed horizontal one, but is inclined downwards and laterally during dorsiflexion, downwards and medially during plantar-flexion. The change-over appears to occur within a few degrees of the neutral position of the talus (Pl. 1, fig. 2). The short intermediate curve that is transitional between the anterior and posterior arcs of the medial profile is cycloidal in form.

The shape of the talus in respect of the curvatures of the trochlear surface appears to be independent of sex and age. Medial and lateral profiles conforming to the adult pattern have been observed in six foetal limbs, ranging in age from 11 weeks (crown-rump length 50 mm.) to 28 weeks (crown-rump length 200 mm.); four were examined by gross dissection, two by serial sections (Pl. 1, figs. 5, 6).

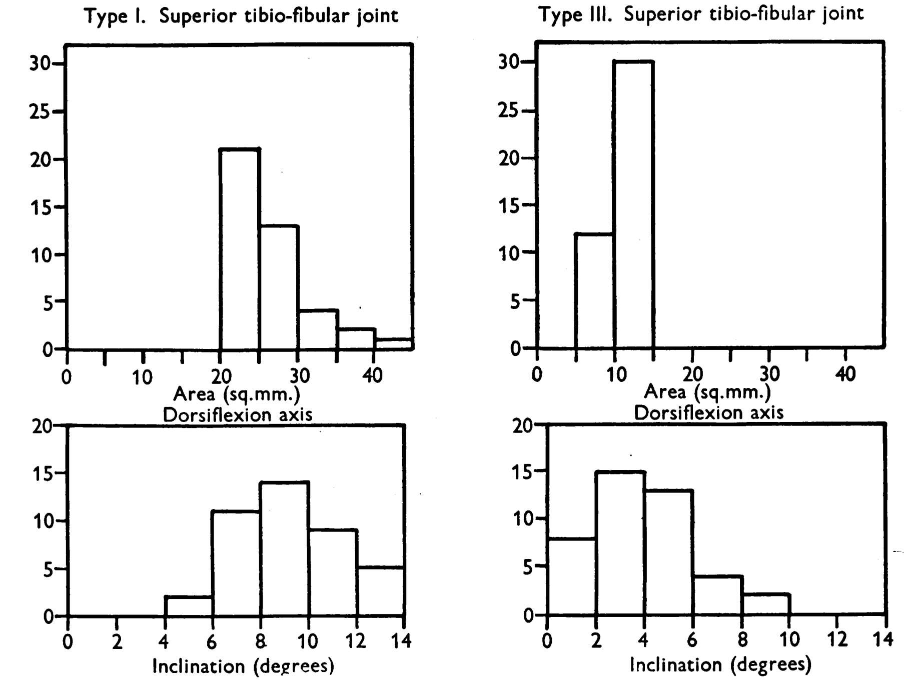
The inclination of the ankle axis shows wide variations. It is approximately horizontal throughout the dorsiflexion phase in some ankles (5 %) and throughout the plantar-flexion phase in others (12 %). Rarely, the medial and lateral profiles form arcs of identical circles (Pl. 1, figs. 3, 4); the axis then remains horizontal throughout both phases of movement (3 % of tali). In the last instance the upper articular surface of the talus may be said to resemble part of a cylinder, in contrast



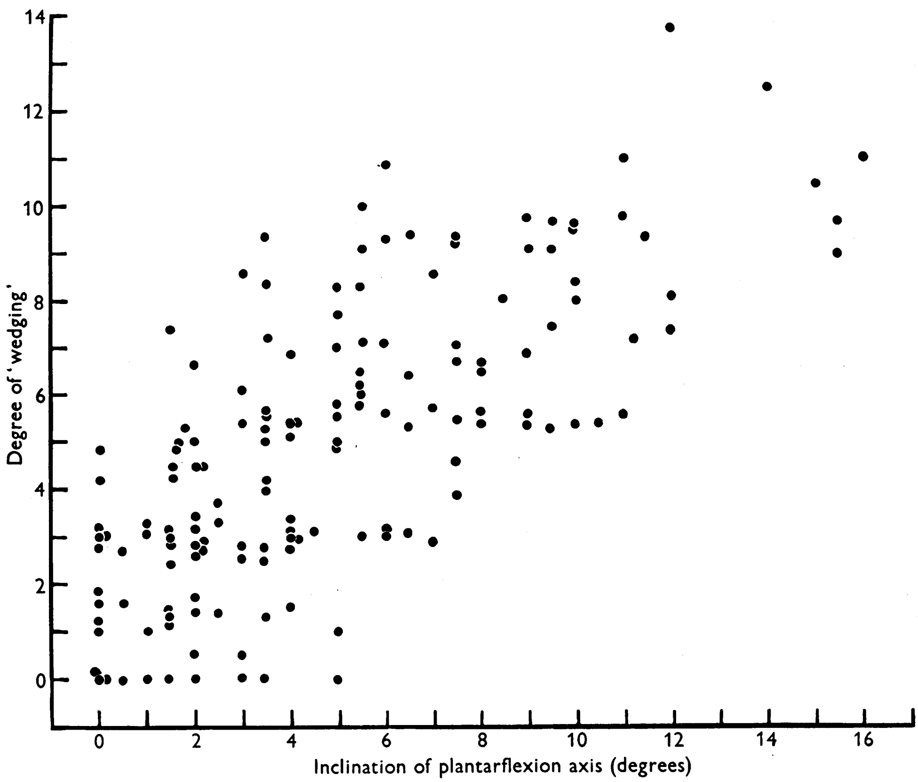
Text-fig. 2. The medial and lateral profiles of the talus in plantar-flexion. The inclination of the plantar-flexion axis (downwards and medially) is obtained by joining the centres of rotation.

to the appearance of the more usual type which may be expressed as consisting of two truncated cones lying side by side, apex to base, a concept which agrees in many respects with that described by Goodsir (1869).

Eleven non-European tali were also examined, but these have not been included in the present series as they were not cartilage-covered specimens. The profiles of these bones suggest a typical 'changing' axis, as described above; in the majority the dorsiflexion axis was steeper and the plantar-flexion axis more nearly horizontal than is usual in the European ankle.



Text-fig. 3. Histograms showing that type I superior tibio-fibular joints are associated with steep dorsiflexion axes at the ankle; type III joints with nearly horizontal dorsiflexion axes.



Text-fig. 4. Graph showing that the degree of 'wedging' of the talus varies with the degree of inclination of the plantar-flexion axis.

RELATIONSHIP BETWEEN ANKLE AXIS, FORM OF TALUS AND MOBILITY OF FIBULA

An unexpected relationship was revealed when the inclinations of the ankle axis, as calculated in 152 specimens, were compared with the 'wedging' of the tali and the mobility of the fibulae.

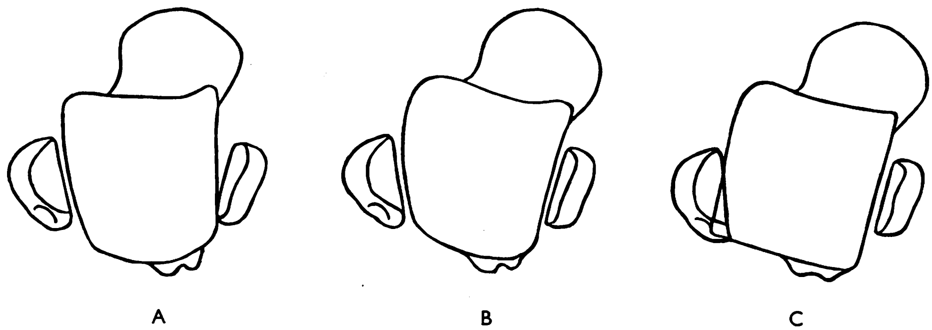
It was found that the mobility of the fibula was related to the steepness of the dorsiflexion axis. Where the superior tibio-fibular joint was large and nearly horizontal (type I), implying a freely mobile fibula, the inclination of the dorsiflexion axis was great; where it was small and steep (type III), implying a relatively immobile fibula, the inclination of the dorsiflexion axis was small (Text-fig. 3).

On the other hand, the degree of 'wedging' of the talus varied with the inclination of the plantar-flexion axis (Text-fig. 4); where this axis was almost horizontal it was found that the talus was parallel-sided (Pl. 1, fig. 8), while a steeply inclined plantar-flexion axis was always associated with a markedly 'wedged' talus (Pl. 1, fig. 7).

DISCUSSION

'Wedging' of the talus and the plantar-flexion axis

The downward and medial inclination of the plantar-flexion axis at the ankle produces a lateral deviation of the front of the talus relative to the tibia as plantar-flexion proceeds, which in turn leads to a separation anteriorly of the articular surfaces on the medial malleolus and the medial side of the talus (Text-fig. 5A).



Text-fig. 5. A, anterior gap at the medial side of the plantar-flexed left talus caused by the inclination of the plantar-flexion axis; B, gap closed by medial rotation of the talus about a vertical axis; C, medial rotation impossible if the talus is parallel-sided.

The lateral side of the talus, on the other hand, retains full contact with the adjoining facet on the fibular malleolus throughout plantar-flexion, since it is very nearly perpendicular to the plantar-flexion axis (Text-fig. 2). This relationship must follow from the general consideration that a rotating surface at right angles to its axis of rotation always maintains its original plane.

The non-alignment developing between the medial articular surface of the talus and the tibial malleolus during plantar-flexion can be neutralized by a medial rotation of the whole talus about a vertical axis.

Such a rotation would require the back of the lateral side of the talus to slope medially if it is to fit accurately against the lateral malleolus when rotation is complete (Text-fig. 5B, C). Examination of the lateral sides of the tali in this series reveals that many are shaped in this fashion. In some ankle joints it appears that this mechanism of medial rotation does not come into play until the final stages of plantar-flexion, for in these the 'wedging' is confined to the posterior one-third of the trochlear surface.

It is clear that this method of maintaining accurate alignment, and thus ensuring stability at the medial side of the talus during plantar-flexion, necessitates a narrowing of the trochlear surface of the talus from front to back. This 'wedging' is therefore greatest in those limbs where the plantar-flexion axis is steep, and minimal where the axis is so nearly horizontal that there is no tendency for the non-alignment to occur.

Rotation of the fibula during dorsiflexion

The medial side of the talus, facing slightly upwards as well as medially, is approximately at right angles to the dorsiflexion axis, which is inclined downwards and laterally (Text-fig. 1). It therefore retains its original plane throughout dorsiflexion, in accordance with the principle stated above.

On the other hand, the plane of the lateral side of the talus must change during dorsiflexion, since it makes an acute angle with the dorsiflexion axis. In order to maintain alignment with this side of the talus, the fibula must rotate laterally about its long axis during dorsiflexion. The actual range of this rotation, and consequently the type of superior tibio-fibular joint, will depend on the steepness of the dorsiflexion axis, becoming greater as the axis becomes steeper.

This rotation has been observed in the living as well as in a freshly amputated limb. Cineradiographic studies in suitable normal subjects indicate a slight rotational movement of the upper end of the fibula during dorsiflexion. This movement is difficult to demonstrate by this technique, however, and it has been observed only twice in a series of seven films. In two patients with wasting of the peroneal muscles, enabling the upper end of the shaft of the fibula to be palpated with ease, the lateral rotation has been readily observed.

The degree of fibular rotation was measured in one freshly amputated limb by means of metal indicator pins driven into the shafts of the tibia and fibula. During forced dorsiflexion, the fibula rotated laterally through 3 degrees relative to the tibia. Subsequent dissection showed that the superior tibio-fibular joint in this limb was large and flat.

The torsional effect upon the fibula produced by the inclination of the ankle axis obviously deserves consideration in the aetiology of fractures about the ankle occasioned by forced dorsiflexion strains.

Other movements at the ankle

It is unlikely that medial rotation of the talus and axial rotation of the fibula are confined exclusively to the plantar-flexion and dorsiflexion ranges respectively.

During plantar-flexion rotation of the fibula may occur in those cases where the lateral side of the talus is not truly perpendicular to the plantar-flexion axis, or where the 'wedging' of the talus is insufficient to maintain alignment at its lateral side as it rotates medially.

In some individuals, medial rotation of the talus, accompanied by medial rotation of the fibula, occurs when the dorsiflexed foot is adducted. This movement also can be observed by means of cineradiography. The report of the Committee on Artificial Limbs of the National Research Council (1947) stresses that such rotational movements of the talus at the ankle are more common than is generally appreciated.

It should be noted that the downwards and lateral inclination of the dorsiflexion axis produces a lateral deviation of the neck of the talus as dorsiflexion proceeds. Provided that no compensatory movements occur at the subtaloid joint, there is a tendency for the foot to deviate laterally as it is dorsiflexed. This deviation is accompanied by lateral rotation of the fibula as already discussed. Both these movements are relative to the tibia; if friction between the foot and the ground, engendered by weight bearing, is sufficient to prevent this lateral deviation, the tibia will rotate medially relative to the foot and the fibula during dorsiflexion.

SUMMARY

1. The trochlear surfaces of 152 cartilage-covered tali have been measured.

2. The medial and lateral profiles of the talus show differences in curvature which indicate that the axis of rotation at the ankle joint is a changing one. This axis is inclined downwards and laterally during dorsiflexion, and downwards and medially during plantar-flexion.

3. The expected correlation between the appearance of 'wedging' of the trochlear surface and the mobility of the fibula—judged by the nature of the superior tibiofibular joint—has not been confirmed. However, correlation has been demonstrated between the steepness of the dorsiflexion axis and the mobility of the fibula, and between the steepness of the plantar-flexion axis and the degree of 'wedging' of the talus.

4. These relationships are discussed in terms of the possible mechanisms involved. It is suggested that mobility of the fibula and 'wedging' of the talus are necessary accompaniments of an ankle axis that is inclined during both dorsiflexion and plantar-flexion.

We are indebted to Prof. D. V. Davies for his constant encouragement and help, to Prof. H. A. Harris and Prof. M. F. Lucas Keene for generously providing material for study in their respective departments, and to Dr Russell J. Reynolds who kindly made several cineradiographic films for our benefit. Our thanks are due also to Mr J. E. Gibbs for technical assistance and to Mr A. L. Wooding for the photographic work.

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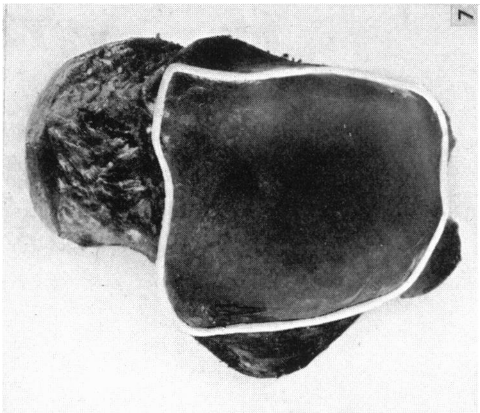

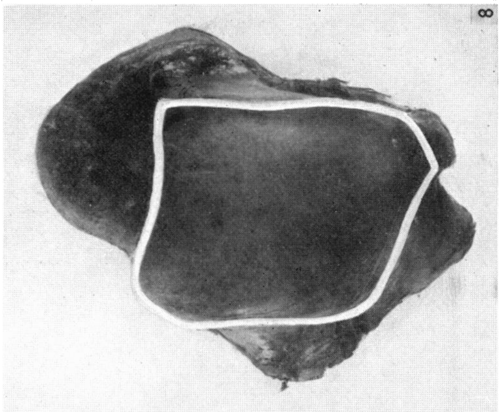

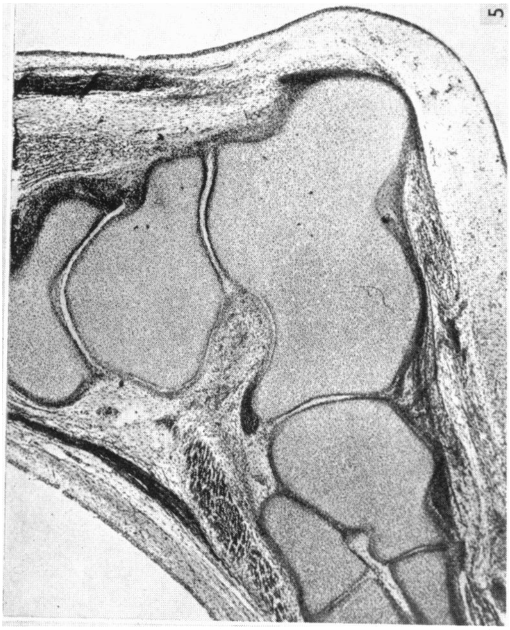

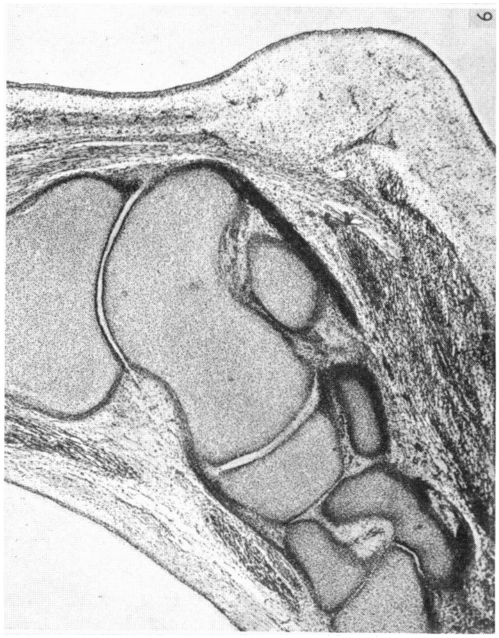

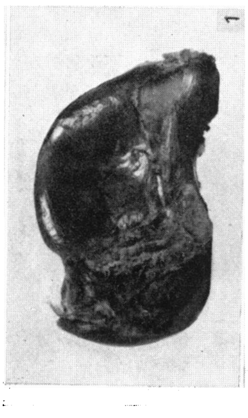

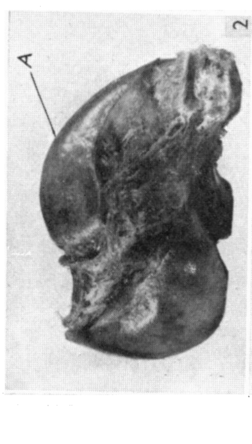

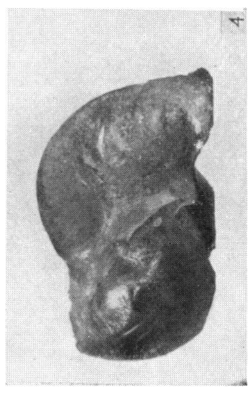

BARNETT AND NAPIER—ROTATION AT THE ANKLE JOINT

EXPLANATION OF PLATE

Fig. 1. The lateral profile of a typical talus.

Fig. 2. The medial profile of the same talus (print reversed for ease of comparison). *A* indicates the highest point on the trochlear surface when the ankle is in the neutral position.

Fig. 3. The lateral profile of a rare type of talus having a fixed horizontal axis of rotation.

Fig. 4. The medial profile of the same talus (print reversed for ease of comparison).

Fig. 5. Section of foetal ankle region, near lateral edge of trochlear surface of talus. Eleven-week human embryo (crown-rump length, 50 mm.). $\times 30$.

Fig. 6. Section taken near medial edge of trochlear surface of talus; same embryo. $\times 30$.

Fig. 7. Trochlear surface of typical talus (shown in profile in figs. 1 and 2).

Fig. 8. Trochlear surface of the talus shown in profile in figs. 3 and 4.